Chapter X

Quantum theory, active information and the mind-matter problem

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Abstract. Bohm and Hiley suggest that a certain new type of active information plays a key objective role in quantum processes. This paper discusses the implications of this suggestion to our understanding of the relation between the mental and the physical aspects of reality.

1. Introduction

Quantum phenomena exhibit a curious combination of wave and particle behavior. For example, in the famous two-slit experiment, electrons arrive one by one at the detecting screen at localized points, suggesting that they are particles. Yet as we keep on watching, the individual spots build up an interference pattern, suggesting that each individual electron ALSO has wave properties. The usual interpretation of quantum theory describes the electron with a wave function. In the minimalist (Bohr's) version, the wave function only allows us to calculate probabilities for finding the electron (as a localized particle) at a given location. In other

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words, the wave function is seen as a part of a mathematical algorithm and is not given an ontological interpretation. However, following von Neumann, many physicists assumed that the wave function provides a complete description of the individual system. This gives rise to the many infamous puzzles of quantum theory, such as the claim that electrons are in two places at once; that cats are alive and dead at the same time; that the world at the macroscopic level is constantly branching into copies ("many worlds"); that to solve these problems the consciousness of the observer has to play an active role. Thus it seems that quantum theory forces us to choose between antirealism or some very counterintuitive realist interpretation.

An apparently more sober realist version of quantum theory was discovered by de Broglie in 1927 and independently rediscovered and further developed by Bohm in 1952 and in subsequent work (Bohm and Hiley 1987, 1993). In this theory the electron is seen as a particle AND a wave. In the two-slit experiment the particle goes through one of the slits. The wave goes through both slits, interferes and guides the particle in such a way that an interference pattern is formed, as many electrons pass through the slit system. It thus seems that we can have a realist interpretation of the quantum theory, without the usual puzzles, such as Schrödinger's cats, many worlds or the consciousness of the observer producing physical reality.

However, the Bohm theory, too, has exotic features. For one thing it implies a non-local interaction between particles at a quantum level, creating a tension with relativity. Also, the wave function for a many-body system lives in a multidimensional configuration space, making it difficult to assume that it describes an ordinary physical field in a 3-dimensional space. To alleviate such problems Bohm and Hiley (1984, 1987, 1993) proposed the radically new notion that the wave function describes not an ordinary physical field, but rather a field of information, which literally informs the energy of the particle.

Such addition of "active information" to our ontology at a fundamental level of physics opens up a number of interesting possibilities for scientific metaphysics (for example, concerning the nature of laws, causation and even the mind-matter relationship; see Pylkkänen 2007, Pylkkänen, Hiley and Pättiniemi, forthcoming; for

discussions of the implications for a variety of issues see Choustova 2007; Haven 2005; Filk 2012; Khrennikov 2004; Maleeh and Amani 2012; Maroney 2002; Smith 2003). In this paper we will describe how the notion of active information at the quantum level might help us to understand the relationship of mind and matter. But before discussing this notion I will first, in the next section, briefly describe Bohm's early work on the mind-matter relation in terms of the notion of the implicate order.

2. The implicate order

Bohm tried to understand the relationship of mind and matter and the nature of conscious experience throughout his extensive work in physics. An important part of this work was the notion of implicate or enfolded order that he developed as an attempt to understand quantum theory and relativity on a common basis (Bohm 1980). Our traditional mechanistic view deriving from classical physics assumes that the universe is made up of basic elements that are independent from and outside of each other and interact mechanically - the order of the classical universe is "explicate". However, according to Bohm quantum theory and relativity challenge this view radically. They imply that "…the whole universe is in some way enfolded in everything and … each thing is enfolded in the whole" (1990: 271). Thus, the order of the quantum-relativistic universe is "implicate" – strictly speaking everything actively enfolds or implicates everything. However, the laws of quantum theory and relativity have a classical limit which means that in the domain of everyday experience things are relatively independent and thus the usual mechanistic view which sees reality as an explicate order works as a useful approximation.

In a Whiteheadian manner, Bohm saw the quantum-relativistic reality as a dynamic movement in which the implicate order prevails - a "holomovement" which is in a constant process of change and development. Things exist as potentialities in the holomovement, from which they unfold into the explicate order and to which they ultimately

fall back to. Things endure in the explicate order, but only for some time. And even while they endure, they do not persist as collections of continuously existing particles. Rather, their endurance is sustained in a constant process of unfoldment and re-enfoldment. (1990: 271)

Bohm was keen to point out that the implicate order also applies to mind. In our stream of consciousness we find a constant flow of thoughts, feelings, desires and impulses which actively implicate each other – for example, a thought may unfold into a desire which in turn may give rise to new thoughts, impulses and so on. Most notably the implicate order prevails among the contents of thoughts, where we customarily say that one thought is implicit in another. A train of thought can be described as a process of unfoldment of a succession of implications (Bohm and Peat 2000: 185). While the Cartesian dualist tradition of Western philosophy has emphasized the difference between mind and matter, Bohm felt that they have the implicate order in common, and are thus at least analogous in an important respect.

However, he also acknowledged that the implicate order was a general scheme rather than a specific theory. As a consequence, it left open many issues, including a more detailed description of how mind and matter are related. He thus felt that the notion of implicate order had to be extended and developed to achieve a more accurate theory of matter, mind and their relationship. He proposed to go significantly towards such an extension by bringing in the ontological interpretation of quantum theory, which he had originally proposed already in 1952, and developed with Basil Hiley and their research students since mid-1970s.

3. The ontological interpretation and active information

There are many different interpretations of quantum theory and these open up different possibilities to approach the problems related to mind and consciousness. Bohm published in 1952 an interpretation that postulates that an electron is always a particle AND a field (and not a particle OR a field, as in most other interpretations). The field guides the motion of the particle. Not surprisingly, the theory has also been called the “pilot-wave” theory in its earlier version due to Louis de Broglie; it

has also been called "(non-local) hidden variable interpretation", "the causal interpretation", "the Bohm theory" or "the ontological interpretation". We adopt here the latter name, as it describes Bohm and Hiley's latest version that is particularly relevant to understanding mind and consciousness (Bohm and Hiley 1993).

The ontological interpretation provides an elegant hypothetical explanation of many mysterious quantum experiments, such as the two-slit experiment, the Schrödinger's cat paradox and Wheeler's delayed choice experiment. However, in his later development of the theory, Bohm realized that there is something very strange and radical in the way the wave affects the particle according to the mathematical description. The quantum wave or field is not pushing and pulling the particle mechanically as a classical field would. Instead, it is only the *form* of the field that matters (mathematically, the field gives rise to a potential, but this depends only on the 2^{nd} spatial derivative (= form, shape) of the field, not on the amplitude (= size) of the field).

Bohm suggested that the shape of the quantum field carries information about the environment of the particle and is literally IN-FORMING or putting this form into the energy of the particle. This is information for the electron, not information for us – we are thus using the notion of information in a more objective sense than is usual. Open the second slit in a two-slit experiment, and the form of the field changes radically (due to interference), and there is a correspondingly dramatic influence upon particle trajectories (so that they build up interference fringes). The situation with the Bohmian electron and its quantum field is somewhat analogous to a ship on autopilot guided by radar waves. The radar waves are not pushing and pulling the ship, but their form carries information about the environment of the ship and this form then informs the greater energy of the ship and guides its motion.

Bohm called such information more generally *active information*. The basic idea of active information is that a form having very little energy enters into and directs a much greater energy. The activity of the greater energy is then given a form similar to that of the smaller energy. While the idea that something like active information should apply at the quantum level may sound radical and implausible, he

emphasized that other instances of active information are familiar to us from many different contexts. We already mentioned radio-controlled devices above, and could add computers and other relevant artifacts. He also suggested that the DNA molecule could be seen as containing active information, which guides various biological processes taking place in the cell. And even in human subjective experience, it is easy to think of situations where the notion of active information applies. For example, assume that you are walking in a dark night and have just heard that a dangerous assailant happens to be in the neighborhood, and are thus exceptionally watchful and alert. You then see a suspicious-looking shadow. If your brain-mind interprets this as "the assailant", meaning "danger!", a powerful physico-chemical activity is likely to start in the brain and the body.

Bohm called such activity where meaning or significance gives rise to and guides more manifest physical activities a "signa-somatic" process. He suggested that we describe a human being in terms of a hierarchy of levels, ranging from "manifest" to "subtle". Each level is assumed to have both a physical and a mental side, but at the manifest levels the physical aspect is more dominant, while at the subtle levels are more mental in nature. Meanings that reach human subjective experience are typically carried by underlying "subtle", high-level physiological processes, while their effects reach downwards in the hierarchy of levels and can be detected in the more "manifest" physical levels, including the visible movement of the human body.

The suggestion that the principle of active information applies all the way from the quantum level to the level of human subjective experience opens up a new way of thinking about the relationship of mind and matter, which Bohm sketched in a number of articles (e.g. Bohm 1989, 1990). He drew attention to the hierarchical structure of the mind, in the sense that given that we are in a certain mental state, it is always possible to become aware of that state from a higher level of mental activity. Once the higher order activity apprehends the meaning of the lower-order state, there is a possibility that a yet higher-order activity emerges, which organizes the lower-order information into a greater whole.

This is somewhat similar to the way the perception of the meaning "danger" can organize the lower levels, including the somatic levels of hormonal and physiological activity - but note that here we are talking about a more subtle kind of organization, where it is in the first place information content that gets organized. In terms of the implicate order one could say that the different levels enfold and unfold each other. A higher level enfolds information about the lower ones; and once the meaning of this information at the higher level is apprehended, this meaning unfolds into lower levels, which shows itself in the way the lower-level information gets organized. Or, as Bohm would put it, meaning *is* the activity of information.

4. The emergence of conscious experience in Bohm's scheme

How is the emergence of conscious experience understood in the Bohmian mind-matter scheme? Bohm did not say much about it, which can be seen as one weakness of his proposals. However, given that his view of the mind emphasizes a hierarchy of levels of mental activity, one natural possibility is to apply some version of a higher order theory of consciousness here (Rosenthal 1997). From his own remarks it seems that he might have favored a higher-order perception (HOP) theory. Indeed, he wrote:

> "…our thoughts may contain a whole range of information content of different kinds. This may in turn be surveyed by a higher level of mental activity, as if it were a material object at which one were 'looking'."

Thus, he talks about the higher level of mental activity "surveying" and "looking" at the lower-order information content. It seems natural to assume that it is such surveying and looking that makes the lower-order information content conscious. "Surveying" and "looking" could be understood as analogous to the spotlight of attention.

But it also seems that Bohm does not explain *why* there is consciousness present in such surveying. Rather it seems that he just

presupposes that we can be conscious of the information content of a given level of thought, in the same way that we can be conscious of the material objects when we look at them. He further notes that we can also become aware of the surveying itself, in a yet higher-order mental activity of surveying. So perhaps becoming conscious of a given content or activity requires that one take a "higher-order step", so that the content or activity in question becomes the object or target of surveying or mental looking. In summary, it seems that consciousness in the Bohmian scheme typically involves a higher-order structure, but we are not given an explanation of the origin of consciousness itself.

So, how might we use higher order theories of consciousness to explain consciousness more fully in the Bohmian scheme? A simple possibility would be to *postulate* that what makes a given mental state (or level of information or mental activity in Bohmian terms) conscious is that there exists a higher level of unconscious information, which has the content that one is the first order mental state or activity. But why would the existence of such higher-order information make the first order mental state conscious? The postulate itself is indeed merely a postulate – it does not explain or make intelligible why the higher order information is able to make the first order information conscious. (For an attempt to apply higher order theory of consciousness in the context of the Penrose-Hameroff approach, see Hameroff, Gennaro and Pylkkänen 2014).

5. Soma-significance

In Bohm's proposal we have a more subtle aspect (information in the quantum field) guiding the behaviour of a more manifest aspect (the particle). We could generalize this to a principle that applies whenever meaning influences matter in other contexts. As already mentioned, Bohm proposed such a principle and called it "soma-significance". In this terminology a process in which meaning acts somatically to organize the more manifest levels of matter is called a "signa-somatic" process. The term "soma-significant" refers to the inverse process, where a physical pattern is significant to a higher or more subtle level (e.g. when one is reading a text, the information is carried by different physical

processes (ink, light waves, neural processes) to higher levels of physical organization where its meaning is apprehended). Bohm (2003) characterizes our existence as a "two-way movement" as follows:

> We emphasize here that nothing exists in this process of soma-significance, except as a two-way movement between the aspects of soma and significance, as well as between levels that are relatively subtle and those that are relatively manifest. It is this over-all structure of meaning … that is grasped in every experience.

He (2003) further illustrates the same point:

> From each level of somatic unfoldment of meaning, there is … a further movement leading to activity on to a yet more manifestly somatic level, until the action finally emerges as a physical movement of the body that affects the environment. So one can say that there is a two-way movement of energy, in which each level of significance acts on the next more manifestly somatic level and so on, while perception carries the meaning of the action back in the other direction.

Such two-way traffic between the mental and the physical is what we need for mental causation. Bohm assumes that each level has both a physical and mental aspect, and hopes this way to avoid the problem of dualism (i.e. the problem of explaining how a non-physical level could possibly interact with a physical level).

6. Extending the ontological interpretation to include mind

Bohm's idea is that mental processes are carried by subtle physical processes - perhaps fields that are analogous to, but more complex than the quantum field. But how could such a "very subtle" field carrying information possibly be able to act upon the more manifest processes e.g.

in the motor cortex? One possibility is that it would act via the quantum field. Indeed, Bohm (1990) writes:

> …that which we experience as mind, in its movement through various levels of subtlety, will, in a natural way ultimately move the body by reaching to the level of the quantum potential and of the 'dance' of the particles. There is no unbridgeable gap or barrier between any of these levels. Rather, at each stage some kind of information is the bridge. This implies that the quantum potential acting on atomic particles, for example, represents only one stage in the process.

It seems to me that Bohm assumed that the more subtle aspects of mind and conscious experience involve more subtle levels of information, which have not yet been discovered by the "3rd person" methods of cognitive neuroscience (although we are aware of at least some of them via our "1st person" introspection). The discovery of the quantum potential is very important as a first guide to what the nature of such more subtle levels could be from the physical side. Indeed, Bohm suggested that by extending the ontological interpretation in a natural way, we could include the subtle mental aspects into the theory. But how can such an extension be done?

> … one could begin by supposing, for example, that as the quantum potential constitutes active information that can give form to the movements of the particles, so there is a superquantum potential that can give form to the unfoldment and development of this first order quantum potential. This latter would no longer satisfy the laws of the current quantum theory, which latter would then be an approximation, working only when the action of the superquantum potential can be neglected. Of course, there is no reason to stop here. One could go on to suppose a series of orders of superquantum potentials, with each order constituting information that gives form to the activity of the next lower order (which is less subtle) (Bohm 1990).

Bohm's radical suggestion thus is that a natural extension of his ontological interpretation of the quantum theory can include mental processes and even conscious experience into a single coherent view. From the point of view of the question about the causal powers of consciousness Bohm's view is particularly promising, for it makes it - at least in principle – possible to understand how conscious experience, via its effects upon information, could make a difference to physical process. If we can provide an intelligible theory about how conscious experience can make a difference to information, Bohm's scheme provides a view of how such informational differences can then affect manifest physical processes (for a preliminary attempt to sketch such a model, see Pylkkänen forthcoming).

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